



## **Ka-band Solid State Power Amplifier (KAPA)\***

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\* KAPA was developed by Lockheed Martin Communications and Power Center under their own internal IR&D funding. An Engineering Test Module Unit was delivered to DS1 and integrated into the Telecommunication subsystem.

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**Deep Space 1**  
**Technology Validation Symposium**  
February 8-9, 2000/Pasadena, CA



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## **Abstract**

Communication subsystems for future missions must be low-mass and enable equivalent if not great data return to the scientific community over the current X-band (8.4 GHz) links. A solution is to increase the downlink frequency to K<sub>a</sub>-band (32 GHz). A major component required is the development of a power amplifier that can boost the transponder's exciter power from 0.5 mW<sub>rf</sub> to over 2W<sub>rf</sub>. This paper describes the basic characteristics of a Lockheed Martin Engineering Test Module Unit that was provided to the New Millennium Program for flight validation on Deep Space One (DS1) mission. Initial in-flight data shows that the unit has been functioning nominally for over the past year (1680 hours of operation accumulated). In addition, the unit has been powered cycled 28 times and has gone through multiple thermal cycles (due to the trajectory combined with autonomous spacecraft maneuvers for optical navigation measurements).

## **Introduction**

The Ka-band Solid State Power Amplifier (KAPA) is one of eight Level-1 technology validation objectives of the New Millennium Deep Space One (DS1) mission. The principal goal of the New Millennium Program (NMP) is to validate selected high-risk, high-benefit technologies in order to reduce the risks and the costs future missions would experience in their use. With successful flight validation of the technology, the risk of using them is substantially reduced. Knowledge gained with the incorporation of the new capability into the spacecraft, ground system, and mission design set a precedence for future missions to benefit from.

KAPA was developed by Lockheed Martin Communications and Power Center under their own internal IR&D funding. An Engineering Test Module Unit was delivered to DS1 and integrated into the Telecommunication subsystem.

**This unit has successfully demonstrated the highest power solid state K<sub>a</sub>-band amplifier ever used for deep space communications.** With the future improvement of ground facilities as well with spacecraft hardware, K<sub>a</sub>-band holds a potential four-fold increase in data rate in comparison with X-band. This is extremely important since a faster data rate translates to less required ground resources/mission operation support and this means reduced project cost. Another benefit of going to K<sub>a</sub>-band is the availability of greater bandwidth. NASA as well as commercial programs recognize this and are developing the technology to move beyond microwave bands which are becoming crowded due to PCS and other emerging information technology ventures.

## **KAPA Description and Flight Qualification**

KAPA's mass was 0.66 kg (this includes input/output isolators, power supply, telemetry circuitry and RF electronics), with a RF output power of 2.2W and a gain of 36 dB.

The unit was qualified to DS1 requirements that include:

- Random Vibration-

20 Hz	0.0322 G <sup>2</sup> /Hz
50-500 Hz	0.2 G <sup>2</sup> /Hz
2000 Hz	0.0126 G <sup>2</sup> /Hz
Overall	13 G <sub>rms</sub>
- Thermal Vacuum cycling from -14°C to +40°C
- Full EMC testing to MIL SPEC 461

Unique features include built-in input/output isolators and engineering telemetry monitors (two gate currents, output drain voltage, and internal unit temperature). Due to the short development time for this unit, Lockheed Martin did not hermetically seal it. After delivery, some accelerated testing on other similar power devices has shown no major degradation after an initial burn-in. The flight unit after 250 hours of

ground operation (both in vacuum and atmosphere) did not show any degradation of operation. We were very cautious not to operate the unit too long in an open atmosphere and never allowed the unit to go below dew point.

The key technology for KAPA is the use of 0.25 micron GaAs Pseudomorphic High Electron Mobility Transistors (PHEMT). The efficiency could have been optimized further with the use of 0.15 micron devices; however, time and resources defined what our final product would be in this fast paced program.

## **KAPA FLIGHT VALIDATION**

The telecommunication subsystem for DS1 was a single string (see Figure 1) as mandated by the project. The primary communication link is on Channel 19 at X-band for both uplink and downlink (7.168 GHz and 8.421 GHz, respectively). As part of the technology demonstration we have an auxiliary  $K_a$ -band downlink (32.155 GHz). The heart of the  $K_a$ -band downlink is the KAPA itself (see Figure 2). The full Telecommunication subsystem was described in [1].

On December 4, 1998 the KAPA was first powered on in-flight (launch of DS1 was on October 24, 1998). Flight operation of the unit has been nominal. As of November 22, 1999 the unit has been powered cycled over 28 times and we have accumulated over 1680 hours of operating time (over a variety of temperature ranges). In the event that the  $K_a$ -band operation was not nominal, it was the responsibility of the flight team to ensure that enough data was available in order to determine what the anomaly could have been. This was accomplished internal and external to the KAPA itself. Internal to the unit temperature sensor, gate currents and gate voltage telemetry are passed to the C&DH subsystem. External to the unit we have RF power detectors monitoring the input RF power and the output RF power from KAPA. This allows us to ensure that the RF drive from the SDST or any intervening component is not responsible for any potential degradation of performance.

## **Validation Criteria**

### **Pre-Flight:**

Development of a 2.5  $W_{RF}$  SSPA which has ~36 dB gain and provides critical engineering telemetry (gate current, drain voltage and unit temperature) for unit performance evaluation during flight.

### **Post Flight:**

#### **Launch to L+25 day**

Due to mission pointing constraints for MICAS a  $K_a$ -band communication link can not be achieved during this period.

#### **> L+25**

Ability to have a  $K_a$ -band communication link is a major validation step.

## Validation Evaluation/Summary

### **Pre-Launch**

<u>Parameter</u>	<u>Achieved</u>	<u>Benchmark (MGS Mission)</u>
Mass*	0.650 kg	>0.600 kg (and does not have input isolator)
RF Output Power	2.2W	1W
Efficiency*	13%	8.7%
Gain	36.4 dB	15 dB

### **Post-Launch (>L+25)**

<u>Parameter</u>	<u>Achieved</u>
RF Output Power	2.16W
Efficiency*	12%
Gain	36 dB

\*including DC-DC converter

The overall performance of the unit has been nominal. Analysis of data has been first order. Mainly the Telecom Mission Operator plots data looking for any potentially trends in addition to being within nominal operating range. There was observed within the range of measurement error ( 0.5 dB) a potential step change in output power. However, no visible trend is apparent at this time.

## Ka-band TECHNOLOGY

The desire to increase the data volume of future systems can be accomplished by going from X-band (8.4 GHz) to Ka-band (32 GHz). Theoretically there is a 16-fold advantage. When one takes into account the realities of weather, spacecraft pointing etc, the potential advantage is predicted to be a factor of 4. The KAPA is a major component required in achieving this important goal. The question now may arise, what does it take to have a Ka-band link? The downlink telemetry is modulated onto a subcarrier and then upconverted to Ka-band in the Small Deep Space Transponder (SDST). From the SDST, the signal may be coupled off to detectors or go directly to the power amplifier to increase the signal strength. The KAPA provides critical this function (see Figure 1). From the amplifier, the signal can be routed through couplers and/or switches to the antenna where it is radiated into free space.

Collecting all the facts presented thus far:

- We understand that Ka-band may enable greater science data return.
- DS1 has validated the operation of the highest power solid state Ka-band amplifier for Deep Space Communications.

Based on this information, a question that can be asked is "did we achieve the potential advantage for Ka-band communications?" Initial results from [2] indicate that future systems could achieve the four-fold improvement based on scaled calculation from DS1 flight data.

## **SUMMARY AND CONCLUSION**

DS1 has successfully demonstrated in-flight the operation of a Ka-band (32 GHz) Solid State Power Amplifier (KAPA) which was an Engineering Test Module Unit provided by Lockheed Martin Communication and Power Center (using their own IR&D funding). This technology in turn has enabled further validation of the Ka-band potential advantage over X-band for Deep Space Communications.

## **ACKNOWLEDGMENT**

KAPA was developed by Lockheed Martin Communications and Power Center under their own internal IR&D funding. An Engineering Test Module Unit was delivered to DS1 and integrated into the Telecommunication subsystem.

Many people have contributed to the success of KAPA and its technology validation activities. The authors would like to acknowledge the following:

### **From Lockheed Martin CPC:**

Mark Karnacewicz  
Sandy Conway  
Mitch Hirokawa  
Bob Novack  
Todd Rena  
Lew Sponar  
William Taft III  
Sam Valenti  
Ken Vaughn  
Larry Newman

**DS1 Flight and Mission Support team:** A large team of operation personnel has labored extensively over the planning and execution of the tech validation activities. The authors will like to acknowledge the participation of the following individuals, without their support the technology validation and characterization effort of the KAPA would not have been successful:

Pam Chadbourne  
Kathy Moyd  
Marc Rayman  
Rob Smith  
Ben Toyoshima

**The work described herein was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.**

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